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CELERITY OF DAM-BREAK WAVES ON RIGID STAGGED VEGETATION

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ABSTRACT

In the context of today's climate change, with extreme events becoming more frequent and more intense, highly unsteady flows are a threat that can no longer be ignored in hydraulic and coastal engineering, since these can lead to human casualties and extensive damage. Impulse waves, storm surges, flash floods and tsunamis are among these unsteady flows, with tragic examples in the last years, including the Indian Ocean tsunami in 2004, Japan Tohoku in 2011 and Indonesia in 2018. These events showed that a deeper knowledge of the underlying physical phenomena is necessary to ensure safety to people and minimize expenses associated with recovery. Due to rarity and complexity of these flows, experimental approaches are often required and in laboratories unsteady flows can be reproduced using dam-break waves (Ritter 1892, Stoker 1958). However, most laboratory tests are conducted on (unrealistic) smooth inverts, hence rising the question on how the bed roughness affects the propagation and the hydrodynamic properties of these flows. Previous studies, including Dressler (1952), Wüthrich et al. (2019) and Nielsen et al. (2022) provided relevant information, but more research is needed to gain a better understanding. In particular, little knowledge is available on the behaviour of these highly unsteady flows propagating through Rigid Stagged Vegetation (RSV), which is representative of forests and other natural areas surrounding built environments.

Based on a large experimental campaign, this research studied the propagation of dam-break waves on rough beds, in the form of various configurations of RSV. Waves were generated in a 14 m long and 0.4 m wide horizontal flume, where a d_0 = 0.4 m impounded reservoir was released through the sudden opening of a gate, as shown in Figure 1. The waves propagated in the downstream horizontal flume, where different roughness configurations are installed. More specifically, the study analysed a smooth plywood configuration and 4 Rigid Stagged Vegetation (RSV) configurations (Figure 2), reproduced using nails with various grid densities and lengths, as detailed in Table 1. Tests were conducted on dry bed, as well as on an initial still water level h_0, which ranged between 7.5 and 50 mm (*i.e.* $0.0188 < h_0/d_0 < 0.125$). Tests on dry bed were repeated 5 times, while tests on wet bed were repeated 10 times. Data were analysed using ensemble-average values. Six Acoustic Displacement Meters ADM (Microsonic TM mic+35/IU/TC, Dortmund Germany) were used to capture the wave profiles in time as well as the wave front celerity C between various ADMs. In this study only the celerities between ADM 5 and 6 are considered, since at this location the bore was fully developed (Buitelaar 2022). Wave propagation was also documented using videos and SLR high speed photographs.

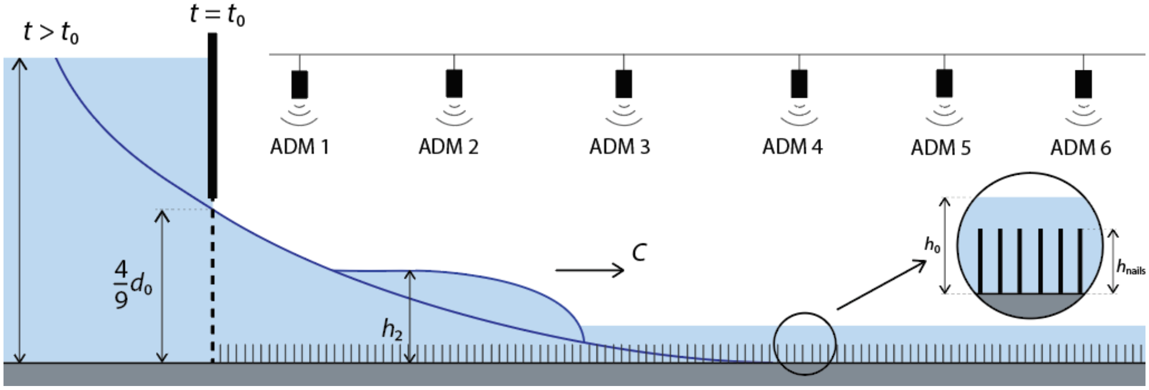

Figure 1. Experimental set-up and definition sketch of the main parameters.

Table 1 – Details of the roughness configurations tested in the present study.

Configuration			h_{nail} [mm]	$\varnothing_{nail}$ [mm]	ρ_{nail} [dm^{-2}]
Reference	R0	Smooth	-		-
Roughness 1	RSV-1	19 mm nails, low density	19	1.6	10.9 (Low)
Roughness 2	RSV-2	19 mm nails, high density	19	1.6	21.8 (High)
Roughness 3	RSV-3	39 mm nails, low density	39	2.4	10.9 (Low)
Roughness 4	RSV-4	19 & 39 mm nails, high density	19 & 39	1.6 & 2.4	21.8 (High)
Roughness 5	RSV-5	39 mm nails, high density	39	2.4	21.8 (High)

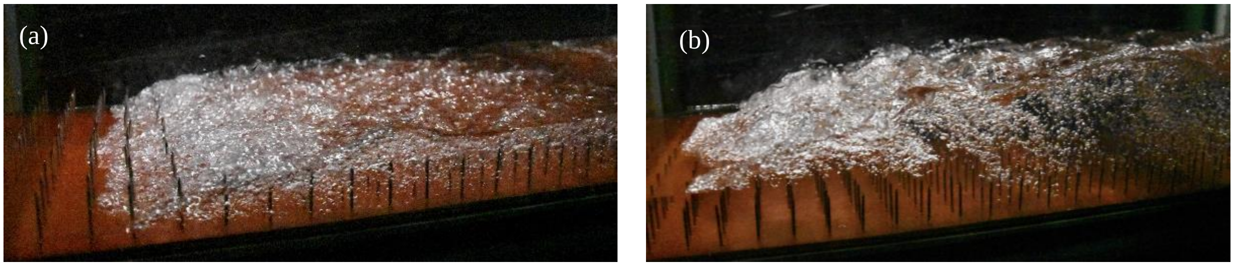

Figure 2. Dam-break waves (d_0=0.4m) on Rigid Stagged Vegetation RSV-3 (long nails, low density): (a) h_0=7.5mm; (b) h_0=50mm.

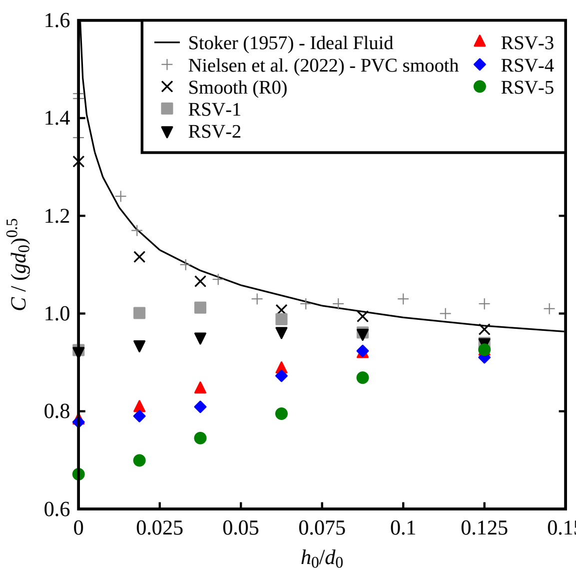

Figure 3. Wave front celerities as function of the initial still water level h_0 for various roughness configurations.

This study focused on wave front celerities. Results for the smooth configuration R0 showed in Figure 3 consistent behaviour with existing theories (Ritter 1892, Stoker 1957) as well as previous studies (Nielsen et al. 2022; Wüthrich et al. 2019). It is interesting to note that for the smooth configuration the presence of an initial still water level ($h_0 > 0$) was responsible for a substantial decrease in wave front celerity, likely associated with the additional resistance imposed by the tailwater. Similarly, for dam-break waves on dry bed ($h_0/d_0 = 0$), the addition of Rigid Stagged Vegetation was also responsible for a decrease in wave front celerity, which dropped from $C/(gd_0) = 1.3$ for R0 (smooth) to 0.65 for the RSV with longer nails and higher density (RSV-5). This confirms a well-known dependence of C on bed roughness that needs to be better understood. However, while both the initial still water layer h_0 and bed roughness had (individually) a reducing effect on the front celerity, data in Figure 3 showed clearly that the simultaneous presence of an initial still water layer h_0 among the Rigid Stagged Vegetation (Figure 2) was responsible for an increase in wave front celerity. This counterintuitive behaviour was particularly visible for the largest roughness RSV-5, suggesting that the simultaneous presence of macro-roughness and still water resulted in a lubrication effect that led to higher celerities compared to the respective dry bed configurations, in line with previous observations by Nielsen et al. (2022). Data in Figure 3 also showed that for increasing tailwater depths ($h_0/d_0 \rightarrow 0.125$), all configurations converged to the Stoker (1957) celerity, suggesting the existence of a threshold above which bed roughness had negligible effect compared to the initial still water layer h_0.

In conclusions, this short study showed that bed roughness in the form of Rigid Stagged Vegetation has a strong effect on the propagation of dam-break waves, especially when combined with the presence of an initial still water layer. This points out the need for additional knowledge and new empirical expressions to support researchers and practitioners in predicting the behaviour of these highly unsteady flows during future extreme events.

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